PLASMA FLOW SWITCH AND FOIL IMPLOSION EXPERIMENTS ON PEGASUS II

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Introduction

Pegasus II is the upgraded version of Pegasus, a pulsed power machine used in the Los Alamos AGEX (Above Ground EXperiments) program. A goal of the program is to produce an intense (>100 TW) source of soft x-rays from the thermalization of the kinetic energy of a 1 to 10 MJ plasma implosion. The radiation pulse should have a maximum duration of several 10's of nanoseconds and will be used in the study of fusion conditions and material properties. The radiating plasma source will be generated by the thermalization of the kinetic energy of an imploding cylindrical, thin, metallic foil. This paper addresses experiments done on a capacitor bank to develop a switch (plasma flow switch) to switch the bank current into the load at peak current. This allows efficient coupling of bank energy into foil kinetic energy.

Figure 1 is a drawing of the Pegasus II facility. Pegasus II machine parameters include a stored energy of 4.3 MJ at 100 kV, a system inductance of 30 nH and current capability of 15 MA. This quadruples the energy of Pegasus I at this voltage. The upgrade was accomplished by replacing the capacitors rated at 10 kJ stored energy at 60 kV with capacitors rated at 30 kJ at 50 kV. The new capacitors have a current capability of 250 kA/capacitor and can stand up to 20% reversal at full charge for a rated lifetime of over 3000 shots. To stay within this voltage reversal specification, series fuses are employed to shut off the current after peak current. The bank itself is composed of two halves charged to opposite polarity. Each half has four modules with eighteen capacitors each. The modules are placed around a radial transmission line with the load in the center of the line. Detonator switches[1] which form an annular aluminum jet that penetrates the polyethylene switch insulation are used to switch the bank. The facility has been used in "direct drive" z-pinch implosions of thin aluminum foils, high magnetic field diffusion experiments, pulse sharpening and switching experiments using a plasma flow switch, and most recently, in liner experiments where the load is an aluminum cylinder with a 0.4 mm thick wall.

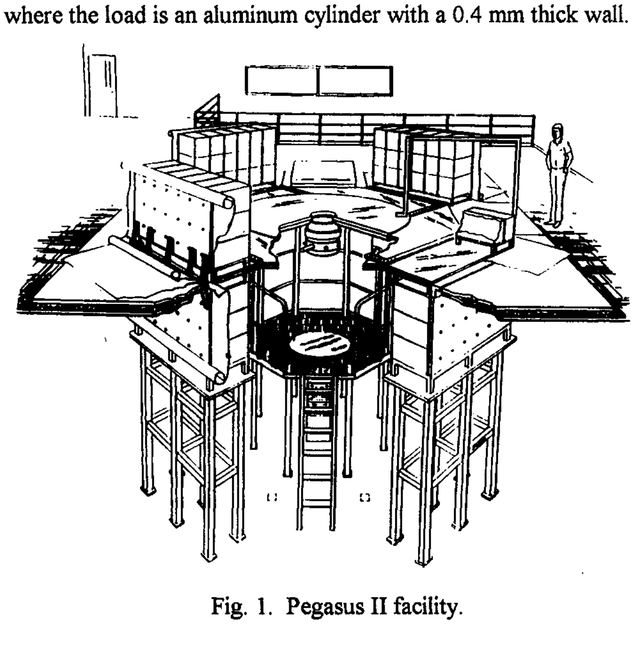

Fig. 1. Pegasus II facility.

Experiment Results

The purpose of the plasma flow switch (pfs) experiments presented here is to develop a switch that demonstrates switching into a high-inductance dummy load. On previous experiments done on Pegasus I,[2] we have observed efficient switching of all of the drive current into a static load at a radius of 5 cm (the foil radius). However, switches driving implosion loads have not been able to develop voltages necessary to drive good implosions (V inferred <10 kV). Speculation is that the switch cannot support a high switching voltage because of plasma either in the power flow channel or bridging the load slot. The experiments done on Pegasus II use a thick copper cylinder of 1 cm radius as the load. Figure 2 is a drawing of the Pegasus II power flow channel showing the location of the pfs in relation to the load slot. The pfs is made of two components: a thin aluminum "bridge" that shorts the power flow channel and a mylar barrier film located just downstream of the aluminum. When the bank is discharged, the aluminum becomes a plasma that conducts the current of the capacitor bank. The plasma then starts to accelerate down the power flow channel via the JxB force acting on the current carrying plasma. The barrier film inhibits the motion of the aluminum plasma until it burns away after about 500 ns (depending on film thickness). The assembled plasma then moves down the channel with a fairly well defined front. As the plasma slug crosses the load slot, (near peak bank current), the current path then includes the load. A simple model for the time to switch the current into the load slot is velocity of the pfs divided by the width of the load slot. In our experiments, this number is 200-600 ns.

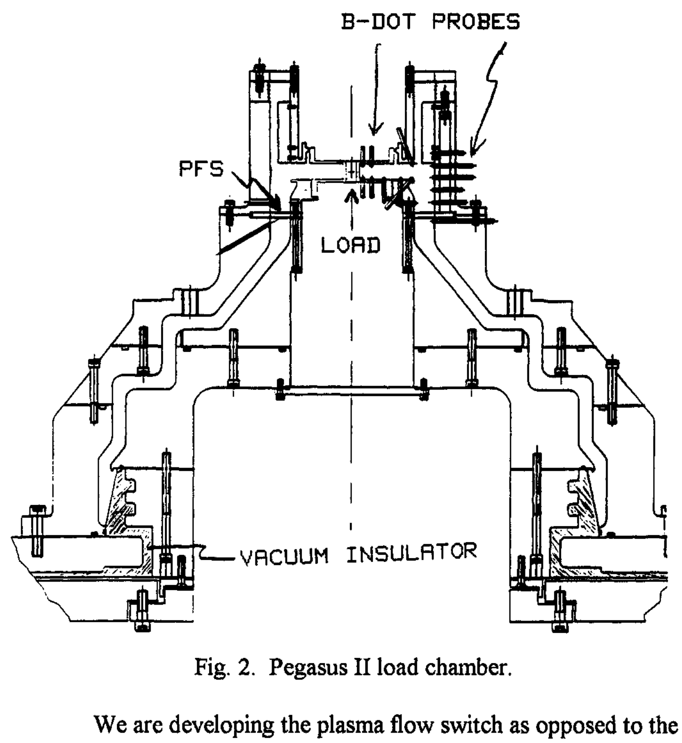

Fig. 2. Pegasus II load chamber.

We are developing the plasma flow switch as opposed to the more commonly used plasma erosion switch because of the relatively

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long rise time (3-6 μs) of our current drivers in use in the AGEX program at Los Alamos, both capacitor bank and explosive flux compression generators. In each of these cases, the conduction time is too long for a demonstrated erosion switch to support the drive current before opening. Plasma erosion switches have sustained the driving current for ≤ 1 μs before opening and our requirements dictate a switch that will conduct many mega-amperes for at least 5 μs.

As noted initially by Turchi,[3] the pfs actually steepens the current front of the current pulse moving down the power flow channel. This is shown in Fig. 3 where current vs. time at different axial positions is shown. Note that the waveform does steepen in time and that there is a "foot" on the rising portion of the current wave. This foot is greatly reduced in amplitude as observed by B-dot probes located in the load slot. The amplitude of this foot and its relation to pfs initiation and pfs mass distribution is under investigation. The mass distribution of the pfs used in Pegasus up to this point is a $1/r^2$ distribution to match the magnetic pressure profile. This has been done on Pegasus I by using a chordal wire array combined with a constant thickness mylar barrier film. The three pfs shots fired on Pegasus II have used a mass-graded aluminum foil instead of the wire array. Results will be compared between these two methods of forming the switch plasma in future experiments.

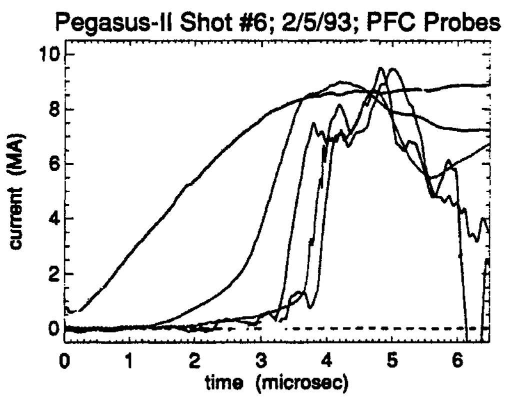

Fig. 3. Current pulse shaping as pfs moves down pfc.

The successful results of the "Quick-Fire"[4] series of experiments done on Shiva Star are well known. The main difference between those experiments and the ones performed on Pegasus have been current levels. Pegasus I operated at about 6 MA with a negative I-dot at switch time whereas Shiva Star operated at about 12 MA with positive I-dot at switch time. Pegasus II is much closer to the parameters of the Shiva Star experiments with current levels approaching 10 MA at switching and switching while I-dot is still positive.

Figure 4 shows current waveforms for two pfs experiments on Pegasus II. These two experiments had pfs masses of 100 mg and 50 mg. The switching occurred at lower current with the lesser mass because of the reduced time to travel to the load slot. Nevertheless, the smaller mass produced better switching, as shown by the solid line in Fig. 4 @ ~3.8 μs, where the current switched onto the surface of the load at r = 1 cm is shown. Note that the current rise for the 1/2 mass switch has less of a "stepping" effect in the current rise. These steps are associated with flux limited flow into the load slot as a fast rate exceeds some flashover value. Another consequence of the lighter pfs is that I-dot is more positive than with the more massive switch since switching occurs earlier in the rise of the current. Figure 5 shows the inferred voltage sustained across the load slot by the pfs during the switching event. Note the rough X10 improvement of the Pegasus II experiments over the Pegasus I results. It should be noted that all of these experiments were performed with the "plasma trap" developed for Pegasus I experiments. This trap was included to prevent a layer of plasma from bridging the load slot and results obtained on Pegasus I supported this design. Calculations have shown that as current levels increase, the effect of the trap may actually be harmful. Future experiments are planned to investigate this effect.

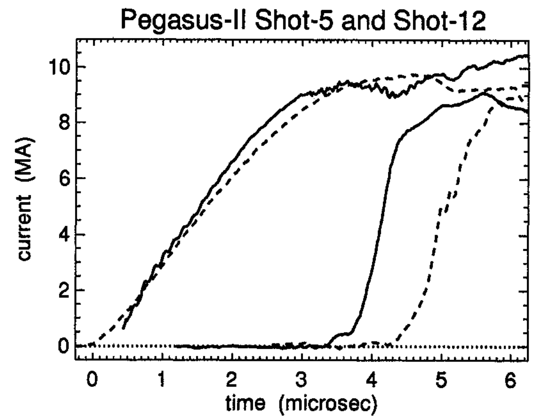

Fig. 4. Bank current and switched current for 50 mg and 100 mg pfs experiments.

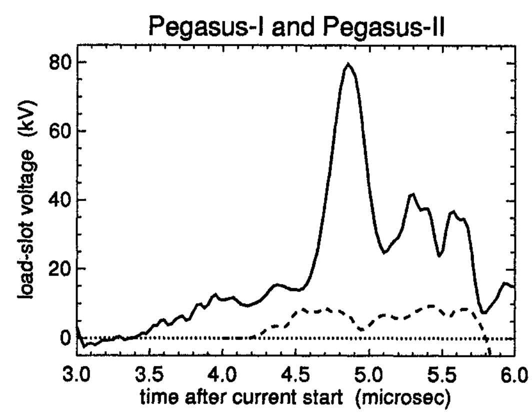

Fig. 5. Switch voltage across load for Pegasus II and Pegasus I pfs experiments.

Summary

The preliminary experiments performed on Pegasus II using a plasma flow switch have been encouraging. We are studying the switch in the absence of an imploding load so that switch behavior is the only variable. The parameters of Pegasus II seem better matched to enhancing the switching performance of the pfs on Pegasus I. Results to date have shown that all of the driving current can be switched into a high inductance, stationary load in roughly 500 ns. Experiments are continuing to optimize the switching characteristics of the plasma flow switch.

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